Evolution of Tropical Cyclone Characteristics

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LONG-TERM GOALS

The long-term goals are to understand how variabilities in the large-scale atmospheric environment and the internal tropical cyclone structure influence tropical cyclone track and intensity characteristics and define how these influences differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that pose difficult forecast situations. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale- or storm-force winds, special attention is given to improving understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet components. As increased understanding leads to improved forecasts of tropical cyclone motion and structure characteristics, a secondary long-term goal of this project is to assess the utility of the tropical cyclone forecast products to shore- and sea-based assets.

OBJECTIVES

Recent research has concentrated on two primary objectives. Climatologically, tropical cyclone formation over the tropical western Pacific during June-October for the Northern Hemisphere summer and during December-March for the Southern Hemisphere summer tends to occur with high regularity (one formation every 6.7 days during June-October). However, extended periods of activity and inactivity occur several times during a typical tropical cyclone season (Harr and Elsberry (1991;1995a,b). If reliable forecasts of extended periods of increased or reduced tropical cyclone activity could be made, maritime operations could be coordinated appropriately. Therefore, increased understanding of the primary factors responsible for initiation, maintenance, and decay of extended periods with tropical cyclone activity or inactivity is a primary objective of the current research.

During a typical June-October season, an average of 12 tropical cyclones undergo extratropical transition (ET) over the western North Pacific. Often, ET results in a fast-moving, rapidly-developing midlatitude cyclone that may contain gale-, storm-, or even typhoon-force winds capable of causing significant damage to coastal and maritime interests. Furthermore, these extreme conditions may occur during summer months when such conditions do not normally occur in association with extratropical cyclones. Therefore, a primary of objective of the current research is to increase understanding of the characteristic structural changes associated with the transition of a tropical cyclone to an extratropical cyclone. Primary emphasis has been on the relationship between the tropical cyclone structure with the midlatitude circulation characteristics into which the tropical cyclone is moving.

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APPROACH

It is hypothesized that the mechanisms responsible for clustering of tropical cyclone activity can be put into a framework of external and internal forcing. An external forcing is identified as a physical mechanism that acts over space and/or time scales different from those associated with the circulation features associated with the tropical cyclone activity or inactivity. For example, the Madden-Julian Oscillation (MJO) has been investigated as providing an external control on tropical cyclone formation over the tropical western North Pacific during the Northern Hemisphere summer and over the tropical western South Pacific during the Australian monsoon season. Tropical cyclone activity/inactivity may also be related to mechanisms that act over similar synoptic space and time scales as the tropical cyclone. For example, formation may be enhanced in the wake of pre-existing tropical cyclones. Also, pre-existing, synoptic-scale disturbances that propagate over time scales similar to tropical cyclones may influence the formation of tropical cyclone activity.

To investigate the structural evolution of a tropical cyclone to an extratropical cyclone, the approach has been to define extratropical transition to occur in two stages, transformation and re-intensification (Klein et al. 2000a). The impact of various factors such as the evolving internal tropical cyclone features (e.g., convective activity, inner-core structure), midlatitude circulation into which the tropical cyclone is moving, and relative roles of upper- and lower-level processes on the transition from a tropical to an extratropical cyclone are then investigated during each stage of the transition process. It is hypothesized that the development of the extratropical cyclone during re-intensification depends on the phasing of the poleward-moving tropical cyclone and a critical region in the midlatitude circulation that contains essential elements for support of extratropical cyclogenesis. The sensitivity of the two-stage process of ET to the interaction between the tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving is examined by numerical experimentation in which only the phasing between the tropical cyclone and midlatitude circulations is altered. The movement of the tropical cyclone into the midlatitudes is then delayed or accelerated to examine the relative roles of tropical and midlatitude features during transformation of the tropical cyclone and re-intensification as an extratropical cyclone.

WORK COMPLETED

As an initial investigation into the framework of external/internal forcing of tropical cyclone activity, the spatial and temporal characteristics of the variability in the 850 mb and 200 mb circulations over the tropical western North Pacific have been defined from the reanalysis data produced by the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) for the period 1958-1998 (Harr and Elsberry 2000b). The variability in the large-scale circulation patterns is defined using a wavelet analysis over a region from 40^{o}S-40^{o}N, 60^{o}E-160^{o}W. The wavelet analysis provides several advantages for describing components of variability in a time-frequency domain. Although the wavelet analysis is applied over the entire data record, the zoom capability of the wavelet transform allows isolation of spectral power during specific time periods and over specific frequency ranges. Of interest in this study is the distribution of spectral power during the June-October period of typhoon activity over the western North Pacific. Additionally, the application of the wavelet analysis over the Indian Ocean/western Pacific regions provides an indication of spatial variability in various frequency bands, which can be related to external and internal influences on tropical cyclone activity. A singular value decomposition (SVD) analysis is used to describe the primary patterns of large-scale

variability associated with the covariance between circulation features identified with predominant peaks in spectral power.

During the Australian monsoon season, the role of external and internal factors on tropical cyclone activity is addressed by examining the interaction between the wind and convection signatures of the MJO and northeasterly cold surges over the South China Sea. A composite analysis (Simms 2000) is based on classification of MJO events and cold surge events based on the NCEP/NCAR reanalysis data between 1979-1998.

The sensitivity of the two-stage process of ET to the interaction between the tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving is examined with the Coupled Ocean Atmosphere Mesoscale Prediction System developed at the Naval Research Laboratory, Monterey. The technique of filtering and vortex removal developed by Kurihara et al. (1995) was modified to allow for a more complete application to the full suite of model variables at all levels. In the modified version, the original wind, temperature, height, and moisture fields associated with the tropical cyclone are removed and re-located to a specified location. The tropical cyclone-related values are placed into a new location via an iterative statistical interpolation procedure. The new location is chosen based on the desired effect, which may be to either delay or accelerate the motion of the tropical cyclone into the midlatitudes and thus alter the phasing with the midlatitude circulation (Klein et al. 2000b).

RESULTS

During the Northern Hemisphere summer, the wavelet analysis identifies variability over three frequency ranges that contain fairly consistent levels of spectral power except for some interannual variability (Harr and Elsberry 2000b). Intraseasonal variability in the period range of 30-60 days is associated with the MJO. Considerable spectral power is also evident over a period range of 10-25 days, which is associated with variability in the structure of the monsoon trough over the western North Pacific. Lastly, considerable power is found in the periods of 2-8 days, which is identified with circulations similar to northwest-propagating disturbances and tropical cyclones.

During periods of high amplitude MJO signal, a strong modulation of the synoptic-scale features by the intraseasonal MJO exists such that MJO-enhanced easterly (westerly) vertical wind shear is associated with enhanced (reduced) synoptic-scale activity. However, considerable variability in the MJO structural characteristics and amplitude is associated with large variability in the modulation of synoptic-scale features by the intraseasonal events. Therefore, the key to defining potential initiation of intraseasonal periods of tropical cyclone activity or inactivity is identification of the variability in the principal features of the MJO that influence the synoptic scale directly. Application of a SVD analysis (Harr and Elsberry 2000b) has identified principal patterns that link MJO-scale circulation and convective features, which are represented using anomalies in outgoing longwave radiation (OLR). Projection of circulation and OLR fields onto these SVD modes has defined a principal MJO signal that may be used to define "climatological" MJO features. These features will then be used to identify the variability in each MJO event that may be identified with the degree of modulation of the synoptic-scale features.

During the Australian monsoon season, the composite analysis based on cold surge events identified a clear relationship between the phasing of the convection signal of the MJO and the occurrence of a cold surge over the South China Sea (Simms 2000). If a cold surge occurred when the active

convection phase of the MJO was at the longitudes of the South China Sea, the cold surge was enhanced along with convection over the Australian monsoon trough. This lead to an increased potential for tropical cyclone occurrence in the Australian region.

An important component of extratropical transition of a tropical cyclone, which has been debated vigorously in scientific meetings, is specification of the primary physical components that define when the tropical cyclone has actually transitioned to an extratropical cyclone. This has important implications for accurate forecasting of the near-surface weather conditions that occur during the transition. Based on structural differences between a tropical and extratropical cyclone, contributions to the formation of frontal boundaries have been defined relative to their linkages with either the decaying tropical cyclone or the pre-existing midlatitude circulation into which the tropical cyclone is moving (Harr and Elsberry 2000a). The stratification of frontogenesis in this manner identified objectively the evolution of the tropical cyclone into an extratropical cyclone. Furthermore, the components of frontogenesis provided an indication of the coupling between the decaying tropical cyclone and the midlatitude circulation, which has proven to be a useful measure of the potential intensity of the extratropical cyclone that formed as a result of the transition process.

The phasing between the decaying tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving was also examined in terms of the distributions of heat and momentum fluxes, and the conversion of available potential energy to kinetic energy (Harr et al. 2000). Although the movement of a tropical cyclone into the midlatitude results in the import of upper-level eddy angular momentum fluxes associated with the juxtaposition of the midlatitude circulation, favorable coupling between the decaying tropical cyclone and midlatitude circulation results in both baroclinic and barotropic conversion of potential energy to kinetic energy through direct solenoidal circulations. An unfavorable phasing results in the destruction of kinetic energy. Harr et al. (2000) defines the primary midlatitude circulation characteristics required for favorable interaction between the tropical cyclone and midlatitude circulation.

Results of numerical experiments, conducted as part of the Ph.D. work of LCDR Peter M. Klein, identified the sensitivity of the re-intensification stage of ET to the phasing between the tropical cyclone and the critical region in the midlatitude circulation (Klein et al 2000b). The critical region was defined as the area in which conditions would be favorable for midlatitude cyclogenesis (e.g., warm advection, 500-mb positive vorticity advection, and upper-level divergence). Experiments based on movement of the tropical cyclone such that the phasing with the midlatitude critical region was either enhanced or reduced confirmed the hypothesis that the re-intensification phase of ET is dependent on the nature of the phasing between the tropical cyclone and midlatitude circulation.

IMPACT/APPLICATIONS

Understanding of the intraseasonal control on tropical cyclone activity and inactivity has the potential for application in a statistical forecast technique to provide long-range outlooks of tropical cyclone activity. If reliable forecasts of extended periods of inactivity (i.e., at least 20 days with no tropical cyclones) could be made, maritime operations could be coordinated to take advantage of the period of reduced threat from tropical cyclones. Applications could be developed for the Southern and Northern Hemisphere tropical cyclones in the western Pacific.

In response to optimum-track ship routing factors, summer and early autumn trans-ocean maritime activity is often conducted at higher latitudes to take advantage of the climatologically favorable warm season wind and wave height conditions and significantly shorter route distances. Therefore, accurate forecasts of the intensity and movement of transitioning tropical cyclones during the warm season is critical. Results of Harr and Elsberry (1998) reveal forecast model sensitivities that may identify instances when large forecast variability might occur. Identification of the importance of phasing between tropical and midlatitude circulations during ET is essential for assessing the impact of an ET event on coastal and maritime regions that lie at the poleward terminus of the primary tropical cyclone tracks in each ocean basin.

TRANSITIONS

It is expected that the investigation of the clustering of tropical cyclone activity will be integrated into a statistical forecast scheme that may be used in an operational setting to provide long-range outlooks (15-25 days) of tropical cyclone activity during the Northern and Southern Hemisphere seasons over the western Pacific Ocean.

Examination of the sensitivity of the re-intensification stage of ET to the phasing between tropical and midlatitude circulations will lead to development of a conceptual model for use by operational forecasters to determine potential midlatitude development and assessment of numerical forecast model representations of re-intensification events.

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